Emergent Behavior and Hydrodynamics of Active Bioparticles

Scientific Achievement

Researchers at Argonne National Laboratory and University of Arizona, Tucson, have developed a new approach to control the concentration and separation of swimming bacteria in confined geometries, such as thin fluid films and channels. The method relies on the collective response of actively swimming bacteria, such as *Bacillus Subtilis, E. Coli* among others, and on the local change of pH levels induced by the transmission of a small electric current through the fluid. As a result of the pH variation, the living cells swim away from the electrodes and concentrate at the middle of the cell, whereas the dead bacteria remain immobile. The concentrated bacteria excite large-scale hydrodynamic flows in the fluid film, and after some time form a dense biofilm. This emergent behavior is captured in the framework of a mathematical model formulated in terms of a two-dimensional equation for local bacteria orientation coupled to the low Reynolds number Navier-Stokes equation for the fluid flow velocity. The collective motion of the bacteria is represented by an additional source term in the Navier-Stokes equation. It is demonstrated that this system exhibits spontaneous formation of large-scale patterns with the characteristic scale determined by the density of the bacteria. The primary mechanism of instability is associated with the shear flow induced deflection of the orientation of the bacteria.

Significance

Our interdisciplinary studies, performed at the intersection of biology and condensed matter physics, have wide-ranging fundamental significance and will give insights into the origin of emergent behavior in systems characterized by competing long-range and short range interactions that are far from equilibrium. Our work may result in entirely new approaches to separate, control, and manipulate bacterial populations and other biological particles. Apart from the fundamental scientific issues, there are several areas of practical application upon which the proposed research would impact directly. Selective self-assembly and manipulation of microorganisms by electric and/or magnetic fields can be achieved in the near future, opening a wide variety of important applications in biomaterials and nanotechnology. The results were selected for an invited talk at the 2006 APS March Meeting. A joint ANL-University of Arizona seed proposal to BES DOE, utilizing these ideas of collective biohydrodynamics, was funded in 2006.

Performers

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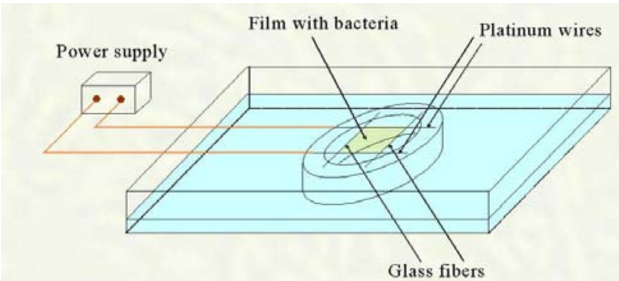
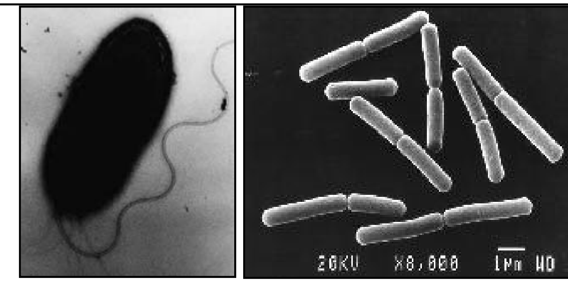
Experimental Setup

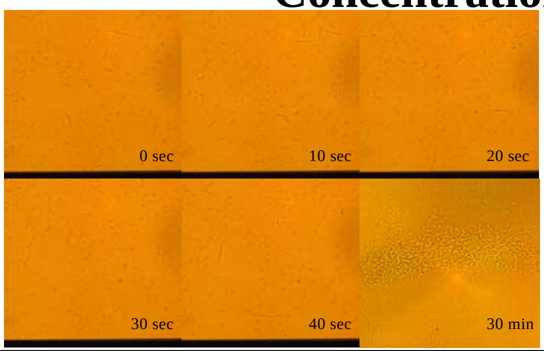


Thin fluid film with bacteria is spanned on four supporting rods. Electric current is used to concentrate the bacteria



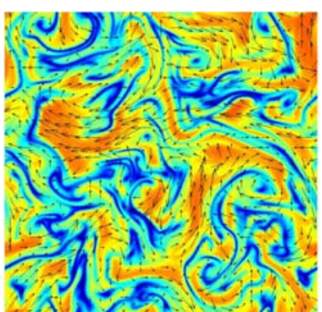
SEM images of individual bacteria *Bacillus Subtilis*

Concentration and Sorting of Bacteria by Electric Current



- Electric current changes pH level near electrodes
- Live bacteria swim away from electrodes towards more comfortable pH level and accumulate in the middle of the cell
- Dead bacteria remain immobile

Mathematical Model of Emergent Large-Scale Flows



- Equations for local bacteria orientation
- 2D Navier-Stokes equation for fluid flows
- Self-propelled particles create flows in the fluid film
- Coupling between shear flow and orientation creates instability

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